# NASA Hypersonic X-Plane Flight Development of Technologies and Capabilities for the 21st Century Access to Space

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**ABSTRACT**
A new family of NASA experimental aircraft (X-planes) is being developed to uniquely, yet synergistically tackle a wide class of technologies to advance low-cost, efficient access to space for a range of payload classes. This family includes two non-air-breathing rocket-powered concepts, the X-33 and the X-34 aircraft, and two air-breathing vehicle concepts, the scramjet-powered Hyper-X and the rocket-based combined-cycle flight vehicle. This report describes the NASA vision for reliable, reusable, fly-to-orbit spacecraft in relation to the current space shuttle capability. These hypersonic X-plane programs, their objectives, and their status are discussed. The respective technology sets and flight program approaches are compared and contrasted. Additionally, the synergy between these programs to advance the entire technology front in a uniform way is discussed. NASA's view of the value of in-flight hypersonic experimentation and technology development to act as the ultimate crucible for proving and accelerating technology readiness is provided. Finally, an opinion on end technology products and space access capabilities for the 21st century is offered.

**1. NOMENCLATURE**

| | |
|---|---|
| ALT | approach and landing test |
| ATD | advanced technology demonstrator |
| CAN | Cooperative Agreement Notice |
| CFD | computational fluid dynamics |
| DoD | Department of Defense |
| DFRC | Dryden Flight Research Center, Edwards, California |
| ELV | expendable launch vehicle |
| FADS | flush airdata system |
| GPS/DGPS | differential global positioning satellite system |
| HTT | high-temperature tunnel |
| INS | inertial navigation system |
| JSC | Johnson Space Center, Houston, Texas |
| KSC | Kennedy Space Center, Cape Canaveral, Florida |
| LaRC | Langley Research Center, Hampton, Virginia |
| LOX | a propellant mixture composed of liquid hydrogen and oxygen |
| MSFC | Marshall Space Flight Center, Huntsville, Alabama |
| NASP | National Aerospace Plane |
| NRA | NASA Research Announcement |
| OSC | Orbital Sciences Corporation, Dulles, Virginia |
| PTO | Participating Test Organization |
| RBCC | rocket-based combined-cycle |
| RTO | Responsible Test Organization |
| RLV | reusable launch vehicle |
| SCA | Shuttle Carrier Aircraft |
| SSTO | single stage to orbit |
| STS | Space Transportation System |
| TPS | thermal protection system |
| TSTO | two stage to orbit |
| WSMR | White Sands Missile Range, New Mexico |

**2. INTRODUCTION**
Through its Department of Defense (DoD) and National Aeronautics and Space Administration* (NASA) joint experimental aircraft programs, the United States has striven to develop advanced aircraft technologies and push the frontiers of flight through the use of unique, experimental aircraft. Since the X-1 beginning in 1945, these aircraft have been designated "X." These nonproduction, nonmission-oriented flight vehicles were designed to be one-of-a-kind flying laboratories that focused on solving special flight problems or developing specific technologies that might or might not find their way onto future applications. High risk and tailored to the special aeronautics problem at hand, these X-planes tackled aeronautics firsts, such as breaking the sound barrier, achieving supersonic and even hypersonic manned flight to better than Mach 6.0, and reaching altitudes in excess of 100,000 to 300,000 ft (ref 1). Technology firsts included variable-sweep wings, forward-swept wings to supersonic speeds, advanced metallic alloys for primary structure, gimbaled jet and rocket engines, and numerous other never-before-flown technologies.

**3. NASA SHUTTLE AND THE QUEST**
During the 1950's and 1960's, the U.S. relied heavily on expendable launch vehicles (ELV) to launch a variety of payloads and humans into Earth orbit. This expensive launch mode limited payload size and weight because of rocket payload bay sizes and, most importantly, payload weight

* NASA was known as the National Advisory Committee for Aeronautics (NACA) in the 1940's and 1950's.

fraction available. Required propellant fractions of up to 89 percent of the launch weight of the vehicle naturally limited what weight fraction could be made available for payload, which amounts to approximately 1.0 to 2.5 percent at liftoff. Launch operations were extensive and complex, resulting in large manpower requirements at fixed launch sites.

Starting in 1963, NASA began to develop the space shuttle as a means of providing recoverable, reusable launch capability with large payload size and lift performance (fig 1). This goal was successfully realized in 1977 when NASA carried out its approach and landing test (ALT) series of the space shuttle atop the Boeing 747 Shuttle Carrier Aircraft (SCA) (fig 2). This shuttle prototype, the *Enterprise*, was not spaceworthy. Launches were limited to subsonic speeds at altitudes of 25,000 ft to test its low-speed recovery characteristics and landing techniques. The first orbital launch of the shuttle Space Transportation System (STS-1) involved the *Columbia* in mid-April 1981.


Figure 1. NASA shuttle landing.

Figure 2. NASA shuttle on the Boeing 747 Shuttle Carrier Aircraft.

Although reusable, the aircraft-like shuttle can not takeoff and accelerate by itself to orbital escape velocity. It still requires lift to orbit by the expendable main propellant tank along with two solid rocket boosters side-mounted to the main propellant tank. These boosters are recoverable after ocean splash down and are reusable after refurbishment. Figure 3 shows the total launch

Figure 3. Shuttle launch configuration.

configuration. Free-flight recovery of the shuttle upon return from orbit is normally accomplished at either the Cape Canaveral launch site at the NASA Kennedy Space Center (KSC) in Florida or at the Dryden Flight Research Center (DFRC) at Edwards Air Force Base in California.

With mostly 1960’s and early 1970’s capabilities, the rapidly aging shuttle fleet is technologically out-of-date, costly, and labor intensive to operate. Thousands of people are required at KSC, Johnson Space Center (JSC) in Houston, Texas, and other facilities to conduct launch and space operations, including recovery back to Earth. Launch costs are controversial and subject to the cost-accounting methodology. Each launch has been estimated to cost at least $400 million, resulting in payload costs of $7000 to $8000 per pound. This is very comparable to the historical ELV experience as shown in table 1 (ref 2). An objective of future reusable launch

Table 1. Expendable launch vehicle payload costs in 1994 dollars (ref 2).

| Launch vehicle | Payload to 160 n.m. due East, lb | Payload, $/lb |
|---|---|---|
| Delta | 10,100 | 3960 |
| Atlas Centaur | 18,100 | 6077 |
| Titan III | 27,000 | 4815 |
| Titan IV | 44,400 | 4054 |
| Ariane | 21,000 | 5238 |
| Long March | 15,200 | 1646 |
| Proton | 38,000 | 1974 |
| Zenit | 28,000 | 2500 |
| Saturn V | 270,000 | 4241 |
| INT 21 | 250,000 | 2533 |

vehicles (RLV), such as the X-33 Advanced Technology Demonstrator (ATD), is to reduce payload costs by a factor of 10 or better to ultimately approximately $200 to $300 per pound. Launch and flight operations for the shuttle are complex and extensive, resulting in less-than-desirable flight turnaround or launch rates with 4 vehicles of at best approximately 8 to 10 launches per year (ref 3).

The NASA desire to carry out its space mission "faster, better, cheaper," as the NASA Administrator has phrased it, has encouraged the agency to not only look for reduced cost and simplified launch systems but also to avoid heavy reliance on supplemental boost systems to carry the flight vehicle to orbit. The NASA goal for RLV's has become a class of self-boosting flight vehicles similar to aircraft which can carry a range of payload types and weight classes to orbit on their own and return to Earth to a horizontal landing. These activities are to be performed with much smaller launch crews, with more rapid turnaround times, and at greatly reduced costs. The critical operations cost reduction issues for these RLV's is to achieve high "on-demand" launch frequency, such as the shuttle's original 25 to 50 flights per year goal, and high launch reliability, better than 98 percent.

The multi-stage-to-orbit shuttle configuration has an intended operational cycle only to the turn of the century (approximately 2012). In recent years, studies have been conducted to replace its complex, expensive operation with either single-stage-to-orbit (SSTO) or two-stage-to-orbit (TSTO) systems that can reduce operational and thus payload costs by a minimum of one order of magnitude. Based on available or envisioned technologies expected within the next couple of decades, numerous national and international studies proved inconclusive as to whether SSTO or TSTO is the most economically viable approach for the foreseeable future over the range of required payload weights. For example, the X-33 ATD is an SSTO concept with large payload potential, and the X-34 aircraft is a TSTO concept for small payloads with two stages within the X-34 configuration itself, air-launched from an L-1011 aircraft.

The U.S. National Aerospace Plane (NASP) X-30, begun in 1985, was an attempt to develop an SSTO concept using multiple propulsion cycles centered around the dual-mode ramjet–scramjet (fig 4). Rather than an incremental technology and flight research program, the X-30 was an attempt at a full-scale operational prototype vehicle system development. This program tried to encompass the complete development range from almost basic research to prototype flight test of the X-30 for SSTO within a single program and time frame. The goal was to achieve first flight by the early 1990's. However, it soon became apparent that the required air-breathing technology set was much too large and evolving at different stages to achieve a mission-capable vehicle even by the beginning of the 21st century without a massive national effort.

Two things were clear from the legacy of the NASP program when it was canceled in November 1994. First and foremost was the realization that a great deal of development work on scramjet propulsion systems, materials, other systems, and thermal management needed to be completed before a vehicle similar to the X-30 could be built. A large part of this development involved the complex engine-airframe integration technology. The crucial ingredient of early flight test and demonstration of incremental subsets of the needed technologies, beginning with the scramjet itself, would be required before going to a full vehicle system development program. Finally, an operational, next-generation, reusable launch system would be needed in the meantime by the beginning of the 21st century to replace the aging shuttle until the air-breathing access-to-space technology set and vehicles could be developed.

For the hypersonic speed regime, a near-term solution could only mean non-air-breathing rocketry in vehicles with improved system performance, reusability, reliability, and much lower operational costs. This need led to the idea to


Figure 4. National Aerospace Plane X-30.

develop the X-33 and X-34 concepts by the end of the 20th century for go-ahead decisions for operational versions early in the 21st century.

### 3.1 Today's Approach Behind NASA's X-Plane Access-to-Space Family

The U.S. National Space Transportation Policy (ref 3) directs NASA to lead the technology development and flight demonstration of next-generation, reusable STS's. The objective is to support government and private sector decisions for operational to-Earth-orbit space vehicles and the commercialization of reusable launch systems and near-Earth-orbit space use of a number of industrial and commercial endeavors.

The overall objective for low-cost, recoverable, and reusable access to space is to reduce payload costs to approximately $200 per pound. Another goal is to increase empty vehicle weight payload fractions toward around 35 percent, which is comparable to military cargo aircraft, such as the C-5A or C-141A. Included in this vision is rapid launch turnaround with operations similar to aircraft and small ground launch crews which do not exceed a few dozen people. Whether vertical or horizontal launch, the recovery is by horizontal landings similar to those executed by airplanes. Such recoveries could be completed at numerous sites around the world.

Realization of this agency goal requires development of new, advanced materials, including new thermal protective systems for increased atmospheric heat loads; lightweight, rugged structural fabrication techniques; and advances in vehicle propulsion systems and other vehicle subsystems, especially in guidance and control. Needed advances in propulsion systems include non-air-breathing rockets and hypersonic air-breathing systems, such as the scramjet and its close relative, the rocket-based combined-cycle (RBCC) engine. Developing new operational techniques and infrastructures to maximize use of these advanced technologies is also required.

Instead of massive developmental programs with expensive, highly system-integrated flight vehicles, future research flight vehicles need to be simpler and less costly. Guided by the NASA Administrator's vision, today's family of hypersonic X-plane concepts share common characteristics and approaches. One commonality that has perhaps the greatest challenge is the use of rapid prototyping concepts to develop and fly vehicles in 2 to 3 years from contractual go-ahead. This challenge will make the programs very aggressive, fast paced and require acceptance of increased risks to achieve program goals. The focus is on flight demonstration of a specific set of technologies and efficient, cost-effective operations rather than full-scale vehicle system development of a production, mission-sized vehicle. As a consequence, the approach emphasizes subscale, unmanned, autonomous, or remotely piloted vehicles to be flight tested at reduced cost and risk. These experimental "X" vehicles are to cost in the tens to low hundreds of millions of dollars instead of perhaps billions as was becoming apparent for building the NASP X-30 vehicle.

Experimental flight vehicles are the critical link in the ultimate validation of design methodologies for future mission applications and of an integrated vehicle system's operational capability. Flight test often reveals and hopefully solves many design issues and systems problems that were not discovered during the initial design and ground test series. In many cases, technologies and their integrated effects can only be truly evaluated in flight. Real operating envelopes and conditions (such as real gas effects, actual atmospheric Reynolds numbers, and accurate enthalpy conditions) can only be found under actual flight conditions. Hypersonic design and analysis codes, databases, and test methodologies are immature for the development of fully operational vehicles, especially in the air-breathing class. Computational fluid dynamics (CFD) codes need further validation for aerodynamics and propulsion above hypersonic speeds, including embedded mathematical models, algorithms, and computational techniques. Ground test techniques and advanced wind-tunnel facilities are needed above Mach 8.0, and again especially for larger scale vehicles or integrated systems. The crucial test of a technology's promise is thus validation through the classical triad of correlation of flight test, ground test, and predictive analysis results.

## 4. X-33 REUSABLE LAUNCH VEHICLE PROGRAM DESCRIPTION, OBJECTIVES, AND STATUS

The X-33 program began with a NASA Cooperative Agreement Notice or CAN (CAN 8-3) issued by the Marshall Space Flight Center (MSFC) Huntsville, Alabama, in April 1996 (ref 4). A contract was awarded to Lockheed-Martin, Palmdale, California, in July 1996 by the MSFC after the competitive phase. The X-33 ATD (fig 5) is a one-half scale lifting body-type flight version of an envisioned operational vehicle known as *VentureStar*. The flight vehicle length is approximately 70.0 ft with a wingspan of approximately 72.0 ft and a small 6.0 ft wide × 12.0 ft high payload bay. The X-33 is launched vertically from Edwards Air Force Base, California. After an overland flight, it can be recovered in a horizontal landing at several planned landing sites at locations ranging from California to Utah to Montana. Fifteen flights are planned as the flight envelope is expanded to suborbital speeds up to Mach 15. Its newly developed J-2S linear aerospike rocket propulsion system (fig 6) has a sea-level thrust rating of 205,000 lb and uses a propellant mixture composed of liquid hydrogen and oxygen (LOX). Two engines are used to propel the X-33. No X-33 return flight to the original launch site is planned; instead, the vehicle will be returned to Edwards Air Force Base atop the SCA.

As with the X-34, the X-33 will fly as an advanced technology demonstrator to investigate and emphasize the operational

Figure 5. Lockheed-Martin X-33 flight vehicle.


Figure 6. X-33 J-2S linear aerospike rocket engine.

feasibility aspects for a full-scale version with a potential 25- to 50-percent reduction in development and production costs and empty vehicle weight payload fractions approaching 10 to 12 percent. (Maximum potential takeoff gross weight payload fraction is about 2 percent.) The X-33 is heavily focused on operational demonstration of a low-cost, reliable aircraft-like SSTO rocket system, requiring a ground crew of 50 people or less. In addition to the 15-flight demonstration under main engine rocket power up to at least Mach 15 with a minimum of two of those flights at or above Mach 15, operational demonstration includes 7-day turnaround from landing to preflight on three consecutive flights and a 2-day turnaround from landing to reflight at least once.

Technology demonstrations include advanced reusable cryogenic propellant tank systems, such as with aluminum-lithium and graphite composite materials. Other advanced technologies to be incorporated include composite primary vehicle structure, new propulsion features of the rocket engine, advanced thermal protection system (TPS) with metallics and ceramics, and advanced vehicle system and structure health-monitoring methods.

First flight is planned for March 1999 (fig 7). A 2-week turnaround for reprocessing the vehicle between flights is to be demonstrated. The DFRC is a flight research Participating Test Organization (PTO) and, along with the contractor team, has formed a flight team at Edwards Air Force Base. DFRC is involved in the design and test support of the X-33 and in the development of the range and range communications. The Air Force Flight Test Center will conduct preflight ground tests and subsystem checkout, flight envelope expansion, X-33 vehicle recovery back to Edwards Air Force Base, and range operations. The flight envelope will be systematically expanded outbound from Edwards Air Force Base in a northeasterly direction toward Montana, up to Mach 15.

## 5. X-34 PROGRAM DESCRIPTION, OBJECTIVES, AND STATUS

The X-34 program began with a NASA Research Announcement or NRA (NRA-14) issued by the MSFC

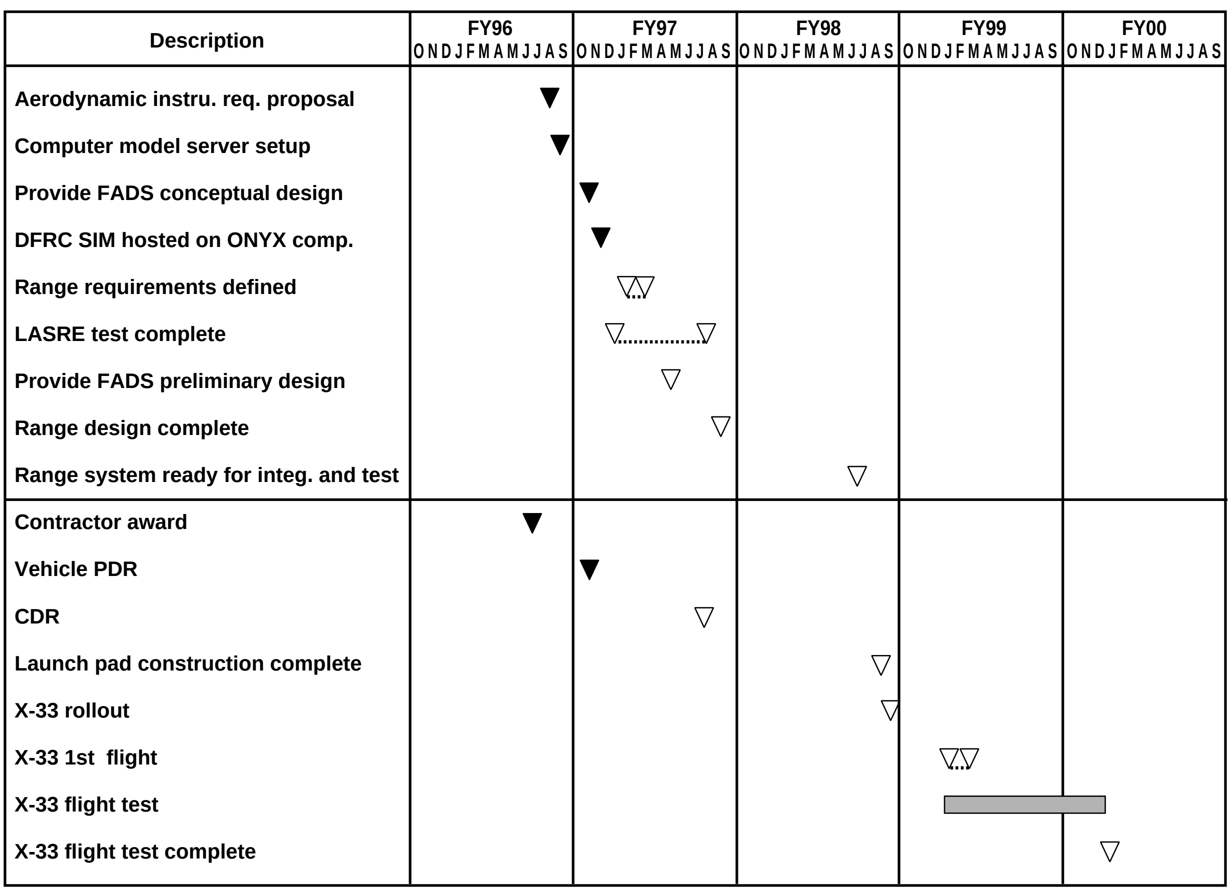


Figure 7. X-33 flight program schedule.

in March 1996 (ref 5). After competitive selection in the summer of 1996, a contract was signed in August with Orbital Sciences Corporation (OSC) of Dulles, Virginia, as the prime contractor to develop and flight demonstrate the X-34 vehicle (fig 8). DFRC is a PTO for this program.

The flight vehicle will be a one-half scale test bed version of an operational concept and is approximately 58.3 ft long with a wingspan of 27.7 ft and height of 11.5 ft. Two vehicles will be built and air-launched at subsonic speeds from the OSC L-1011 aircraft (fig 9). The X-34 will be rocket-boosted by a single NASA MSFC-developed Fastrac rocket (fig 10) to Mach 8.0 at or above an altitude of 250,000 ft. Rocket thrust rating will be 60,500 lb, using a LOX and kerosene propellant mixture.

Flight operations for the first two flights is planned at the White Sands Missile Range (WSMR), New Mexico, within 4 months of each other, including air-launch and landing recovery. An optional phase for operational demonstration of this aircraft-like concept with up to 25 flights in 1 year is also planned as a follow-on effort out of either WSMR or KSC.

Operational demonstration objectives include up to 25 autonomous flights per year to a recoverable landing with low-cost operation, small ground crews, and rapid flight vehicle turnaround. Safe abort capability to an alternate landing site or under emergency flight termination conditions, such as engine out, propellant dump, or subsystem failure, is also planned for demonstration. In addition to the operational flight envelope (Mach 8.0 to or above an altitude of 250,000 ft), the X-34 is to flight demonstrate such anticipated flight environments as landing in crosswinds up to 20 knots and subsonic flight through rain and fog.

Technology demonstration objectives include composite structures for the airframe; propellant tanks and cryogenic systems; and propellant system lines, ducts, and valves. Other technologies include advanced TPS, advanced low-cost avionics, rapid low-cost flight software development tools, and integrated vehicle health-monitoring systems with advanced sensors and software algorithms. Autonomous flight control and guidance and navigation will be provided by an integrated inertial navigation system (INS) and a differential global positioning satellite system (GPS/DGPS). Airdata will be furnished by a fuselage-mounted Flush Airdata System or FADS. The vehicle also will have the potential to act as a hypersonic test bed for other advanced propulsion concepts, such as the rocket-based combined-cycle engine, the pulse detonation wave rocket engines, and other advanced materials and system.

First flight is scheduled for September 1998 at WSMR with a MSFC and OSC flight team. After the second flight in January 1999, a decision will be made as to whether or not to conduct the next 25 operational demonstration flights and, if so, where. These flights will have a nominal turnaround of approximately 2 weeks, but plans include demonstrating a surge capability of two flights in 24 hr. Potential flight-test sites for that phase include the KSC and DFRC.

## 6. ROCKET-BASED COMBINED-CYCLE ENGINE AND FLIGHT VEHICLE DESCRIPTION, OBJECTIVES, AND STATUS

The RBCC engine is the ultimate integration of air-breathing and rocket propulsion cycles into a single configuration or flowpath. It combines the ramjet and scramjet air-breathing engine cycles in the high supersonic to mid-hypersonic speed range with an integral rocket system that can perform as a low-speed system in the subsonic to supersonic range and in the high hypersonic range above the scramjet operating regime. The MSFC RBCC program began in the summer of 1996 with the selection of four engine companies to pursue advanced ground and potentially flight development of candidate engine concepts. These companies include Aerojet, Kaiser Marquardt, Rocketdyne, and Pratt & Whitney. In addition, Pennsylvania State University provides support in CFD analysis and component laboratory tasks.


Figure 8. OSC X-34 flight vehicle.


Figure 9. OSC L-1011 Pegasus launch aircraft.

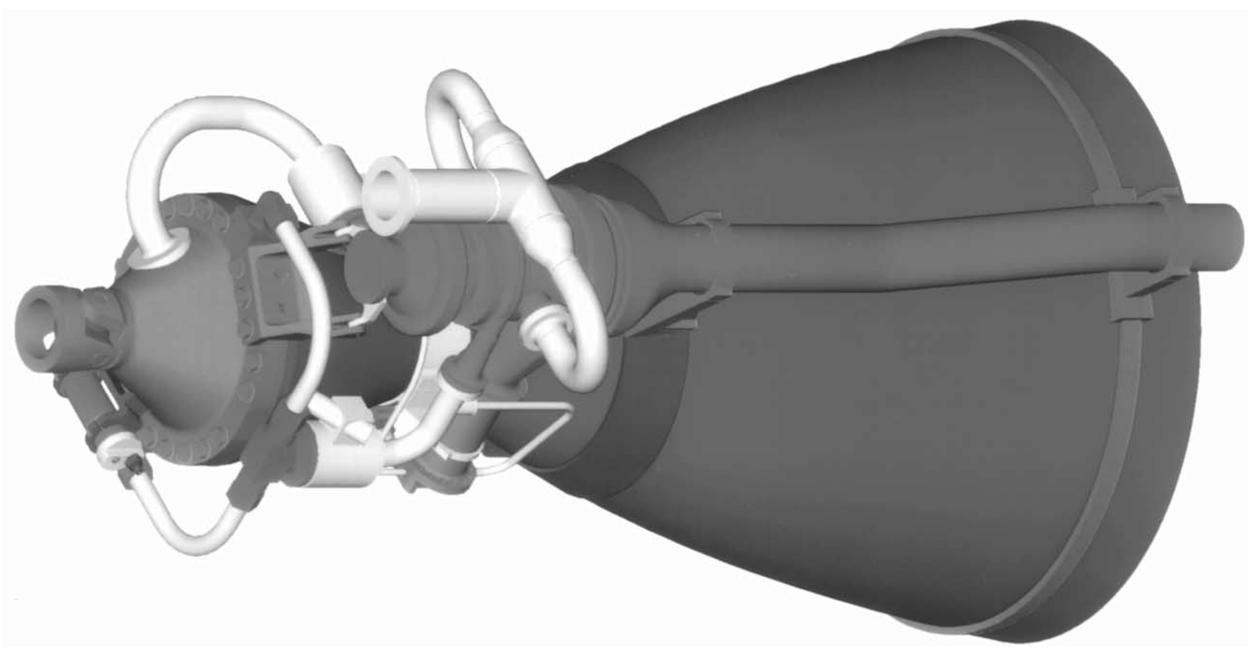

Figure 10. NASA MSFC Fastrac rocket engine. (Drawing courtesy of Marshall Space Flight Center, Huntsville, Alabama.)

A prototype aircraft is being studied as a possible follow-on flight research program to develop integrated designs of large-scale versions of the RBCC with an airframe. If such an integrated system were built, it would not occur until after the turn of the century, depending on NASA budgets and outcomes of preliminary studies. Current discussions include from two to four fairly large flight vehicles costing several hundred million dollars each. In the meantime, MSFC is seeking opportunities to fly smaller scale versions of the RBCC engine on existing program vehicles, such as the Hyper-X or X-34. Unlike the RBCC flight vehicle, the Hyper-X and X-34 vehicles are not optimally integrated airframes for the RBCC but would serve as simple airframe test beds to obtain measured data under true flight conditions.

The initial technology objectives center on evaluation of the integrability of multiple engine modes to smoothly transition over the largest practical speed range up to orbital speeds. An additional objective involves designing flight-weight engine structures and materials that could be carried on to airborne test platforms. Basically, the low-speed system consists of air-augmentation of a basic rocket through an inlet up to approximately Mach 3. At that point, the rocket would be throttled down to allow an air-breathing ramjet cycle to take over operation from approximately Mach 3 to Mach 6. At this point, the scramjet cycle would take over to Mach 10 or above. Beyond approximately Mach 10, the air-breathing flowpath would be closed off by the inlet and transition back to rocket operation. The rocket cycle would then use its onboard oxidant to achieve final orbit insertion.

In addition to planned wind-tunnel ground tests over the next 4 years, studies are considering captive-carry flight tests of some concepts on such flight platforms as the SR-71 aircraft up to Mach 3.0 at dynamic pressures up to approximately 800 to 1000 lb/ft$^2$. Current plans center on engine-only ground tests beginning in 1997 through 1999. Possible SR-71 flight tests would begin in late 1998 or later. Prime candidates out of this test phase could be flight tested on the Hyper-X or the X-34 around the year 2000. Follow-on, large-scale testing on an integrated RBCC flight vehicle may occur after 2001.

**7. HYPER-X PROGRAM DESCRIPTION, OBJECTIVES, AND STATUS**

The Hypersonic Experiment or Hyper-X vehicle is being developed in a phase 1 effort to flight validate the air-breathing, dual-mode scramjet at speeds up to Mach 10.0. It is a joint project between NASA Langley Research Center (LaRC) of Hampton, Virginia, and NASA DFRC. DFRC is the Responsible Test Organization (RTO) for this program.

Using a NASA baseline vehicle design and wind-tunnel ground tests, a competitive phase for fabrication and development of the four flight vehicles was held in the fall of 1996. A contract was awarded in mid-March 1997 to begin a 9-month vehicle fabrication phase. The small, expendable vehicles (fig 11) will be approximately 12.0 ft long, have a 5.0-ft wingspan, and include a single hydrogen-fueled scramjet engine. The simple

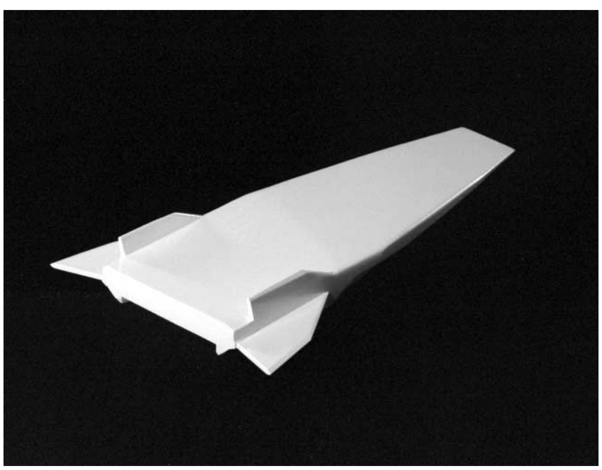

Figure 11. NASA Hyper-X flight vehicle.

airframe is of cold structure design overclad with TPS. The engine is not actively cooled other than water-cooled leading edges and inlet ramp door, and the combustor is of copper heat-sink construction . It is rocket-boosted to its flight-test regime between Mach 5.0 and Mach 10.0 using the Orion 50S first stage of the OSC Pegasus launch vehicle (fig 12). The entire launch stack is air-launched from the NASA DFRC B-52 carrier aircraft (fig 13).

The variable engine geometry normally required for an air-breathing engine to cover a wide speed range, such as that for the Hyper-X, will be resolved by using incrementally fixed geometry engine designs for each discrete aim Mach number test condition. The airframes will be of a single external

Figure 12. OSC Pegasus launch vehicle.

Figure 13. NASA B-52B carrier aircraft with Pegasus booster.

aerodynamic shape. This design simplifies the vehicle system and reduces costs. An open–closed inlet ramp door will be the only variable engine geometry to allow inlet starting. This inlet door will be closed on the rocket-boost ascent and after the engine test phase for descent and flight-test termination.

In addition to the limited wind-tunnel ground tests and design analysis efforts planned as with the X-33 and X-34 for correlation with flight measurements, the Hyper-X program has the unique plan of full-scale wind-tunnel testing of the first flight vehicle at Mach 7.0 in the LaRC 8-ft High-Temperature Tunnel (HTT) facility in the early spring of 1998. The Mach 5.0 vehicle will also be tested in the 8-ft HTT before its actual flight. The vehicle test will include the complete operating systems, including operational test of the scramjet engine with hydrogen fuel.

The test stack configuration will be launched by the B-52 airplane at nominally Mach 0.8, at an altitude of 40,000 ft, and over the water off the California coast. Flight phase termination is planned on or near San Nicolas Island and the Channel Islands offshore from Los Angeles, California. At this time, there are no plans to require recovery of the flight vehicles from a potential water impact; however, such plans are not excluded.

Unlike the X-33 and X-34, the Hyper-X program focuses on technology flight validation rather than operational demonstration. No operational mission is envisioned for this purely research vehicle. The Pegasus first-stage booster is merely intended to transport the experimental vehicle to its test conditions because the scramjet cannot operate by itself below the high supersonic to hypersonic speed regime. Primary technologies consist of the scramjet and its in-flight performance and the engine-airframe integration methodology. Through flight-to-ground data correlation of ground-test and flight-test results with pretest predictive analysis, a key objective is to develop and validate hypersonic air-breathing vehicle design methods, tools, and databases to be used for future air-breathing flight vehicles.

Aim flight-test conditions for the engine evaluation phase are planned at Mach 5.0, Mach 7.0, and Mach 10.0 to afford direct correlation with ground tests. First flight will be with the Mach 7.0 vehicle followed by the Mach 5.0 vehicle and finally both Mach 10.0 vehicles. One Mach 10.0 configuration will represent an accelerator engine configuration, and the other will represent a cruise version. Nominal test dynamic pressure is 1000 lb/ft$^2$ which corresponds to an altitude of approximately 100,000 ft. Small amounts of gaseous hydrogen fuel will be silane piloted for at least 5 sec of stabilized engine operation. This test sequence will be followed by engine shutdown and an unpowered descent for additional aerodynamic data down to subsonic flight conditions.

The first flight vehicle is in fabrication with completion expected by the end of 1997. Figure 14 shows the schedule. One vehicle per year thereafter will be built for subsequent flights of one per year. After the NASA LaRC 8-ft HTT wind-tunnel test in the spring of 1998, the first flight vehicle will be delivered to DFRC for preflight preparations beginning in May 1998. After additional ground tests, system checkout, and booster integration, the first flight is planned for December 1998.

## 8. UNIQUE YET COMMON TECHNOLOGY PATHS AND THEIR SYNERGY

These programs are tackling similar, related hypersonic technologies brought about by the common flight envelopes, similar thermal environments, and ultimate mission applications. Yet unlike the NASP X-30 program, no single program is attempting to combine the broad spectrum of technologies possible. Such an attempt would result in greatly increased costs, program complexity, and developmental lead times and in unachievable objectives. These programs are separated into two major classes: near-term operational concepts for a range of payload classes that can capitalize on more mature rocket propulsion technology and other concepts to equivalently progress air-breathing technologies that can be

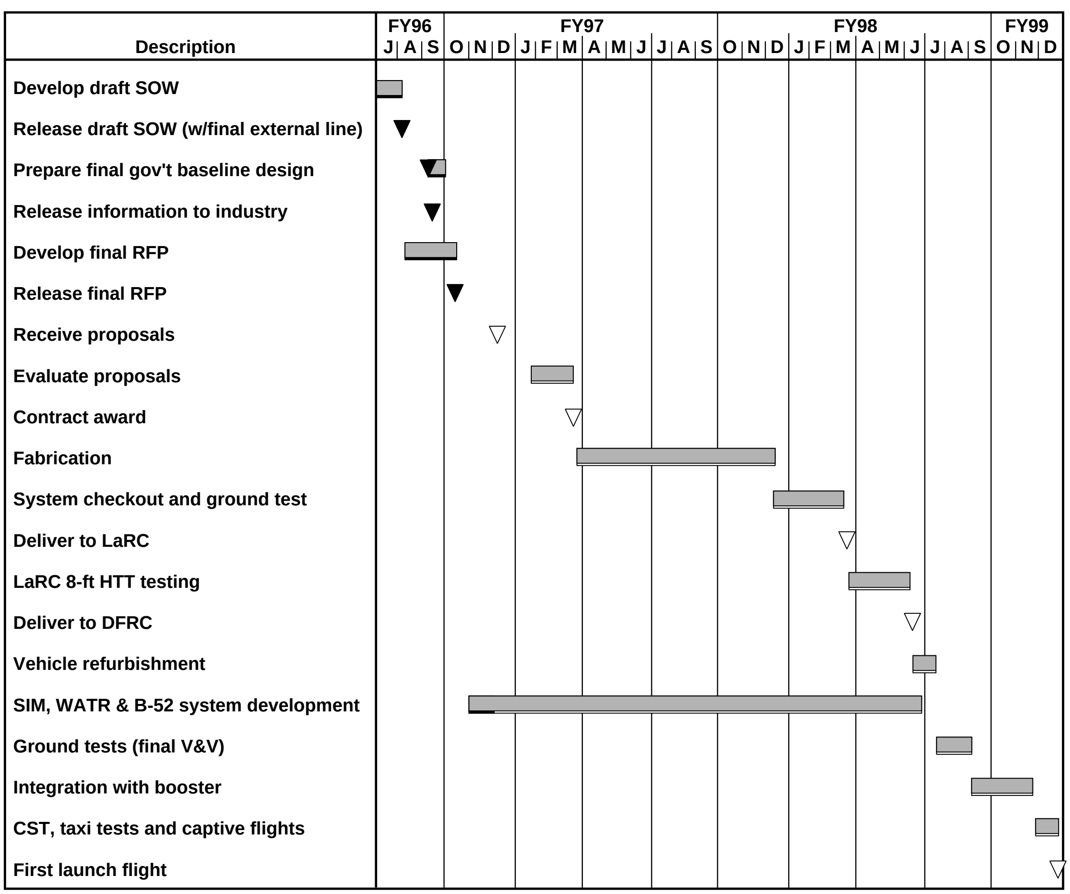


Figure 14. Hyper-X flight program schedule as of February 1997.

applied in the long term future for air-breathing space access. For example, this approach leaves the Hyper-X program to isolate and focus on the air-breathing scramjet technology question without having to dilute efforts and funds with other needed technologies, such as advanced composites, that the X-33 and X-34 can pursue.

The combined fabric of the programs produces a technology synergy which can be shared now within the planned projects or reserved for future vehicle applications. The idea is akin to a divide-and-conquer approach to solving the myriad of technological and operational problems. The immediate benefit of this approach is obtaining near-term operational low-cost, reusable, highly reliable access-to-space vehicles for the turn of the century, while continuing to pursue the ultimate goal of air-breathing access-to-space vehicles. Only air-breathing concepts offer significant promise of large reductions in required propellant fractions, increased payload fractions, and reduced-size vehicles with operations and infrastructure which are similar to aircraft.

## 9. CONCLUDING REMARKS

One lesson from the National Aerospace Plane program and other hypersonic research programs is that technologies and vehicle system concepts must be taken to early flight as the ultimate crucible of their viability and validation. This fact is true for all access-to-space, low-cost, reusable system candidates whether they be powered by non-air-breathing rockets or one of several air-breathing concepts. Another lesson learned is that such complex systems and highly integrated technologies are best tackled in a systematic, incremental series of steps in complimentary programs rather than in a very large, costly single operational prototype vehicle development effort. Too many technical unknowns and programmatic complexities exist to try to address the many issues, immature technologies, and design methods in a single massive program. The NASA family of experimental hypersonic X-vehicles is not only breaking down the complex technical issues into manageable pieces, resulting in reduced cost of experimental concepts, but also is achieving near-term program synergy and increased numbers of interim, at-hand solutions. Only time will bring out the best operational systems, hopefully in time to supplant the aging NASA shuttle fleet.

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